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SOLVER USER'S GUIDE

VERSION 2.2

DYNAMIC RESPONSE ANALYSIS
OF
SINGLE DEGREE OF FREEDOM
SYSTEMS

by

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CONTENTS

OBJECTIVE

The objective of this study is to present the theory and the application of the Newmark-beta method for solving single-degree-of-freedom (SDOF) dynamic problems.

SCOPE

The SOLVER program applies the Newmark-beta method for solving SDOF systems. The SDOF system can be described in terms of a nonlinear stiffness with separate descriptions for the initial response and rebound. Mass and viscous damping can be included as constants or given a nonlinear description. The loading can be arbitrary and include multiple peaks and negative phases.

BACKGROUND

In civil engineering studies, many problems can be reduced to simplified analyses. Specifically, the dynamic behavior of individual members and certain combinations of these members can be treated as SDOF systems. An example of a SDOF system is shown in Figure 1. SDOF systems are a quick and economical way to evaluate a dynamic system and, therefore, are useful for parametric studies. In these problems, the response of interest is primarily the fundamental mode and can be described in terms of some gross behavior (e.g., centerline deflection). Further assumptions include simplified loadings and linear elastic structural response.

Much has been published on the response of linear elastic SDOF systems to triangular, step, and sinusoidal loadings ranging from impulsive to static (Ref 1). In blast design many problems can be described in terms of SDOF systems, but their loadings are complex (e.g., multiple pulses, positive and negative phases, and bilinear). Also, the structural response is generally well within the plastic regime which is not modeled properly with linear elasticity. Therefore, blast design may require a more general SDOF solution which will reduce or eliminate some of these assumptions.

CAPABILITIES

The SOLVER program calculates the dynamic response of a user prescribed SDOF system and loading. The SDOF system is defined by the user as a piecewise linear resistance-deflection curve. An example of a piecewise linear resistance-deflection curve is shown in Figure 2. Within this piecewise linear curve the mass and damping can be specified. This

allows for mass and damping to vary as a function of the resistance-deflection curve. The loading is also defined as a piecewise linear load-time history. Both the resistance-deflection curve and the loading can be defined in a positive and negative sense. The SDOF system will respond to a positive loading using the positive resistance-deflection curve. Multiple loadings can be prescribed. One requirement in the user definitions is that the units (e.g., length, force, time) remain consistent throughout the input (including defaults). The units and examples of consistent units are shown in Table 1.

The solution used in elastic-plastic solutions is the Newmark beta method. The user can define the time step and Newmark's beta and gamma or use the defaults. A beta of 0.25 and gamma of 0.5 are the defaults, and produce the constant-average-acceleration method which is unconditionally stable. A beta of 1/6 and a gamma of 0.5 produce the linear acceleration method which is conditionally stable. SOLVER allows initial deflection, velocities, and accelerations to be defined.

The time step defaults to one fiftieth of the natural period. This value is satisfactory for elastic calculations, but is normally too large for plasticity. The accuracy of the solution is dependent upon the time step chosen, therefore, it's prudent to test several time steps.

The SOLVER program provides a means of analyzing structures using general SDOF techniques. The theory is described in the next section, followed by the user's manual and execution instructions. Example problems and comparisons to other numerical solutions are given in Appendixes A through E.

THEORY

Resistance-Deflection Curves

The SDOF system is defined by the user as a piecewise linear resistance-deflection curve with each point being considered a yield point (resistance, yield deflection). The stiffness is calculated as the slope of the linear segment (Figure 2). Each point can be input in terms of any combination of two: stiffness, resistance, and yield deflection (except in the case where stiffness is set to zero, a yield deflection must be input). The resistance-deflection curves can be prescribed for both the positive and negative resistance regions, with the restriction that the first segment of each region has a positive stiffness.

When rebounding, the initial stiffness is used until zero resistance is reached. Then the opposite region resistance-deflection curve is shifted over and used as shown in Figure 3. This is tantamount to isotropic hardening.

Upon reloading, the program "remembers" the last deflection (at unloading) and uses the initial stiffness to return to the "saved" deflection. Once it reaches this deflection the stiffness appropriate for that segment of the resistance-deflection curve is used (i.e., it doesn't follow the originally prescribed curve).

2

The last point (i.e., largest yield deflection) prescribed on either resistance-deflection curve is defined as the ultimate. If this deflection is reached during the solution, the program stops. If the analyst is unsure as to the maximum deflection expected and wants a complete solution, the last deflection should be made arbitrarily large.

Incremental Newmark-Beta Method

For dynamic solutions, SOLVER uses the Newmark equations:

$$\dot{u}_{t+\Delta t} = \dot{u}_t + \left[(1 - \gamma) \ddot{u}_t + \gamma \ddot{u}_{t+\Delta t} \right] \Delta t \tag{1}$$

$$u_{t+\Delta t} = u_t + \dot{u}_t \Delta t + \left[\left(\frac{1}{2} - \beta \right) \ddot{u}_t + \beta \ddot{u}_{t+\Delta t} \right] \Delta t^2 \tag{2}$$

where: $\ddot{u}_{t+\Delta t}$ = acceleration at time t+Δt

$\ddot{u}_t$ = acceleration at time t

$\dot{u}_{t+\Delta t}$ = velocity at time t+Δt

$\dot{u}_t$ = velocity at time t

$u_{t+\Delta t}$ = deflection at time t+Δt

u_t = deflection at time t

β = Newmark's beta

γ = Newmark's alpha

Δt = time increment

Equation 2 is solved for the acceleration at time t+Δt in terms of the unknown deflection:

$$\ddot{u}_{t+\Delta t} = \frac{1}{\beta \Delta t^2} (u_{t+\Delta t} - u_t) - \frac{1}{\beta \Delta t} \dot{u}_t - \left(\frac{1}{2 \beta} - 1 \right) \ddot{u}_t \tag{3}$$

Equation 3 is inserted into Equation 1 resulting in an expression for velocity at time t+Δt in terms of the unknown deflection:

$$\dot{u}_{t+\Delta t} = \frac{\gamma}{\beta \Delta t} (u_{t+\Delta t} - u_t) + \left(1 - \frac{\gamma}{\beta} \right) \dot{u}_t \tag{4}$$

$$+ \left(1 - \frac{\gamma}{2 \beta} \right) \Delta t \ddot{u}_t$$

3

The equation of motion defined for time $t+\Delta t$ is:

$$M_n \ddot{u}_{t+\Delta t} + C_n \dot{u}_{t+\Delta t} + K_n u_{t+\Delta t} = P_{t+\Delta t} \tag{5}$$

where: M_n = mass at segment n of the resistance-deflection curve

C_n = viscous damping coefficient at segment n of the resistance-deflection curve

K_n = stiffness at segment n of the resistance-deflection curve

$P_{t+\Delta t}$ = external load at time $t+\Delta t$

Equations 3 and 4 are inserted into the equation of motion resulting in an expression in terms of the unknown displacement:

$$M_n \left[\frac{1}{\beta \, \Delta t^2} (u_{t+\Delta t} - u_t) - \frac{1}{\beta \, \Delta t} \dot{u}_t - \left(\frac{1}{2 \, \beta} - 1 \right) \ddot{u}_t \right] \tag{6}$$

$$+ C_n \left[\frac{\gamma}{\beta \, \Delta t} (u_{t+\Delta t} - u_t) + \left(1 - \frac{\gamma}{\beta} \right) \dot{u}_t + \left(1 - \frac{\gamma}{2 \, \beta} \right) \Delta t \, \ddot{u}_t \right]$$

$$+ K_n (u_{t+\Delta t}) = P_{t+\Delta t}$$

The term $K_n u_t$ is subtracted from both sides, thus allowing the system to be solved in terms of a incremental displacement. This equation is rearranged with all the unknowns on the left hand side:

$$K_{eff} (u_{t+\Delta t} - u_t) = P_{eff} \tag{7}$$

where: K_{eff} = effective stiffness

$$= a_o M_n + a_1 C_n + K_n$$

P_{eff} = effective load

$$= P_{t+\Delta t} + M_n (a_2 \dot{u}_t + a_3 \ddot{u}_t) + C_n (a_4 \dot{u}_t + a_5 \ddot{u}_t) - K_n u_t$$

$$a_o = \frac{1}{\beta \, \Delta t^2}$$

$$a_1 = \frac{\gamma}{\beta \, \Delta t}$$

$$a_2 = \frac{1}{\beta \, \Delta t}$$

4

$$a_3 = \left(\frac{1}{2\beta} \cdot 1\right)$$

$$a_4 = \left(\frac{\gamma}{\beta} - 1\right)$$

$$a_5 = \frac{\Delta t}{2}\left(\frac{\gamma}{\beta} - 2\right)$$

The incremental deflection is solved by:

$$\Delta u = u_{t+\Delta t} - u_t = \frac{P_{eff}}{K_{eff}} \qquad (8)$$

where: Δu = deflection increment

The total deflection is an accumulation of the incremental deflections:

$$u_{t+\Delta t} = u_t + \Delta u \qquad (9)$$

The acceleration is calculated using Equation 3. This acceleration is used in Equation 4 to calculate the velocity. To avoid any drift (since the Newmark equations are only approximations) the acceleration is then recalculated using the equation of motion:

$$\ddot{u}_{t+\Delta t} = \frac{1}{M_n}\left(P_{t+\Delta t} - C_n\dot{u}_{t+\Delta t} - K_n u_{t+\Delta t}\right) \qquad (10)$$

In order to handle multiple segments on the resistance-deflection curve, the points where the stiffness changes are defined by a yield deflection. When this deflection is exceeded, the calculation is stopped and the acceleration, velocity, and deflection are set back to the previous increment. The increment of the deflection required to bring the system to the yield point is defined:

$$\Delta u_n = \Delta u - \left(u_{t+\Delta t} - u_{yield}\right) \qquad (11)$$

where: Δu_n = deflection increment attributed to n^{th} stiffness

u_{yield} = yield deflection

5

The time step required to bring the system to yield is approximated as the fraction of the original time step and is defined as:

$$\Delta t_n \cong \frac{\Delta u_n}{\Delta u} (\Delta t) \qquad (12)$$

where: Δt_n = time step required to reach the yield deflection using the nth stiffness

The equation of motion is solved using this new time step and properties associated with the nth segment of the resistance-deflection curve. This results in a deflection that is close to the yield but not exact. The system stiffness is then updated to the $n+1$ segment and the remaining portion of the time step is calculated:

$$\Delta t_{n+1} = \Delta t - \Delta t_n \qquad (13)$$

where: Δt_{n+1} = remaining portion of the time step

The second time step is used for solving the equation of motion with the new portion of the updated resistance-deflection curve. The time step is then reset to the original step size until another yield deflection is reached. A flow chart showing how this solution scheme works is shown in Figure 4. Examples of how this compares with other techniques are given in Appendix B.

It is important to note that the approximation of the time step around a yield point is not exact. This could result in some drift from the true theoretical resistance-deflection curve, especially for multiple stiffnesses. The drift, however, can be reduced by choosing a smaller time step.

Load-Time Histories

The load-time histories are given by the user as piecewise linear curve. Up to 10 load cases can be defined for each structure with a maximum of 20 points for each load-time history. The program linearly interpolates between points for each time step. It is recommended that the times of the load points be multiples of the time step to avoid any clipping. An example of clipping is shown in Figure 5.

The load-time history must be defined at time of zero. If the load at time of zero is anything but 0.0 the problem becomes an initial value problem with the initial acceleration defined as:

$$A_i = \frac{P_o}{M_{eq}} \qquad (14)$$

where: A_i = initial acceleration

P_o = load at time 0.0

M_{eq} = equivalent mass

If the solution goes beyond the last point defined in the load-time history the program assumes a zero load.

USER'S GUIDE

Line 1. Heading (2A5,7A10)

Note	Column	Variable	Entry
(1)	1 - 5	HEADNG (1)	Keyword for program execution .EQ. SOLV, program proceeds .EQ. STOP, program stops
	6 - 80	HEADNG (2)	Problem description

Notes:

(1) The program can read and execute multiple data sets and therefore requires a keyword to start and stop. An example of the data file is shown in Figure 6.

Line 2. Analysis Control Line (2I5,5F10.0,I5)

Note	Column	Variable	Entry
(1)	1 - 5	METHOD	Solution procedure .EQ.0, defaults to 1 .EQ.1, Newmark-beta method (EL-PL)
(2)	6 - 10	LODCAS	Number of load cases .EQ.0, defaults to 1 .GT.10, not admissible
(3)	11 - 20	DTIME	Time Step .EQ.0.0, 1/50 of natural period
(4)	21 - 30	TLIMIT	Time Limit for Solution .EQ.0.0, calculates to maximum only
(5)	31 - 40	GAMMA	Newmark's gamma .EQ.0.0, defaults to 0.5
(5)	41 - 50	BETA	Newmark's beta .EQ.0.0, defaults to 0.25

7

(6)   61 - 65   NPRINT   Print Control
                                                     .EQ.0, defaults to 1
                                                     .EQ.1, print every step
                                                     .EQ.-1, print significant
                                                            changes
                                                     .EQ.N, print every Nth step

Notes:

(1) The Newmark-beta method can be used for elastic and elastic-plastic
     analyses.

(2) A number of independent loading conditions can be prescribed for
     the same SDOF system. A maximum of 10 load cases can be prescribed.

(3) The default is useful only for elastic analyses and not recommended
     for elastic-plastic analyses. The default chosen is 1/50 of the
     natural period and is calculated using the initial, positive mass
     and stiffness. The calculation for the default time step is given
     as: $TSTEP=(PI/25.0)*(EQMASS(1)*SMASS/STIFF(1))^{1/2}$. For elastic-
     plastic analysis, it is recommended to make several analyses, halv-
     ing the time step until the response doesn't change significantly.

(4) A time limit of 0 will stop the program once the first maximum is
     calculated (and the solution starts to rebound). It is recommended
     for rebound solutions to first calculate the maximum and then
     choose a time limit as some multiple of it. Solutions for complex
     loadings (e.g., multiple peaks) will require an estimate based upon
     the loading.

(5) The default values for the Newmark parameters are for the
     unconditionally stable constant-average-acceleration scheme. The
     linear acceleration scheme is obtained by choosing BETA = 0.1667
     and GAMMA = 0.5.

(6) The default prints every step. For long calculations or when the
     time step is small, output could get large. It is recommended that
     for these calculations, the option for significant changes is
     chosen (i.e., NPRINT = -1).

8

Line 3. Initial Conditions (3F10.0)

Note	Column	Variable	Entry
(1)	1 - 10	DEFLTN	Initial deflection
	11 - 20	VELOCT	Initial velocity
	21 - 30	ACCELR	Initial acceleration

Notes:

(1) Values can be input as an initial value problem (e.g., instanta-
neous shock impulse can be modeled using an initial velocity).
Input for deflection, velocity, and acceleration results in a
restart problem. If the initial deflection exceeds any number of
yield points, the program looks for the associated portion of the
resistance-deflection curve (i.e., it will skip portions of the
curve).

Line 4. Stiffness Control Line (2I5,2F10.0)

Note	Column	Variable	Entry
(1)	1 - 5	NSTIF1	Number of points defining the positive resistance-deflection curve. Points must be defined in the positive-positive quadrant (Figure 2). .EQ.0 defaults to 1
	6 - 10	NSTIF2	Number of points defining the negative (rebound) resistance-deflection curve. Points must be defined in the negative-negative quadrant (Figure 2).
(2)	11 - 20	SMASS	Total structural mass .LE.0.0 not admissible
(3)	21 - 30	DAMPNG	Percent of critical damping expressed as a fraction. Must be less than 1.0

Notes:

(1) The number of points describing the positive region and the nega-
tive region is required (see Figure 2). The origin of the
resistance-deflection curve is defined as point (0.0, 0.0). The
convention is a positive loading uses the positive resistance-
deflection curve. If no rebound is to be calculated then the

rebound region does not need to be defined (e.g., for a positive
load with no rebound, the negative region does not need to be
input).

(2)   The total structure mass must be input and can be modified in the
      piecewise portions of the resistance-deflection curve.

(3)   The percent critical damping is input as a fraction (i.e., 1.0 =
      100%, 0.5 = 50%, etc). Critical damping is calculated as $D = 2.0*$
      $(STIFF(1)*EQMASS(1)*SMASS)^{1/2}$

Line 5. Initial Resistance-Deflection Points (I5,5F10.0)

      Read NSTIF1 data lines here.

Note	Column	Variable	Entry
(1)	1 - 5	MODE(N)	Mode for point definition .EQ.0, defaults to 1 .EQ.1, stiffness and resistance given .EQ.2, deflection and resistance given .EQ.3, stiffness and deflection given
	6 - 15	STIFF(N)	Stiffness STIFF(1).LE.0.0, not admissible
	16 - 25	RESIST(N)	Resistance .EQ.0.0, not admissible
	26 - 35	DEFYLD(N)	Yield Deflection
(2)	36 - 45	EQMASS(N)	Fraction of mass (SMASS) .LE.0.0, not admissible
(3)	46 - 55	DAMP(N)	Fraction of damping (DAMPNG)

Notes:

(1)   Each point defines a linear segment (from the last point). NSTIF1
      points are read here. The points are defined by any combination of
      two: stiffness, resistance, or deflection. MODE defines the
      combination the program will read. If the stiffness is set to
      zero (except the first), a deflection must be input (MODE must
      equal 3).

(2)   This fraction will be multiplied by the total mass (i.e., SMASS,
      line 4) to determine the effective mass acting for this portion of

the resistance-deflection curve. Therefore, an input of 1.0 = 100% of SMASS, 0.5 = 50% of SMASS, etc. The natural period is calculated using the initial effective mass (i.e., EQMASS(1)*SMASS).

(3) This fraction is multiplied by the total damping (i.e., DAMPNG, line 4) to determine the effective damping acting for this portion of the resistance-deflection curve. Therefore, an input of 1.0 = 100% of DAMPNG, 0.5 = 50% of DAMPNG, etc.

Line 6. **Rebound Resistance-Deflection Points** (I5,5F10.0)

Read NST1F2 data lines here.

Note	Column	Variable	Entry
(1)	1 - 5	MODE(N)	Mode for point definition .EQ.0, defaults to 1 .EQ.1, stiffness and resistance given .EQ.2, deflection and resistance given .EQ.3, stiffness and deflection given
	6 - 15	STIFF(N)	Stiffness STIFF(1) .LE.0.0, not admissible
	16 - 25	RESIST(N)	Resistance .EQ.0.0, not admissible
	26 - 35	DEFLYD(N)	Yield Deflection
	36 - 45	EQMASS(N)	Fraction of mass (SMASS) .LE.0.0, not admissible
	46 - 55	DAMP(N)	Fraction of damping (DAMPNG)

Notes:

(1) See Line 5 notes.

Line 7.0. Load Sets

Read LODCAS sets of data lines here.

Line 7.1. Load Control Lines (2I5)

Note	Column	Variable	Entry
(1)	1 - 5	NUMLOD	Number of load case .LE.0, not admissible .GT.LODCAS, not admissible
(2)	6 - 10	NUMLPT(NUMLOD)	Number of load points .LE.0, default to 2 .GT.20, not admissible

Line 7.2. Load Points

Read NUMLPT(NUMLOD)/4 data lines here.   (8F10.0)

Note	Column	Variable	Entry
(3)	1 - 10	BTIME(1,1)	First load time must equal 0.0
	11 - 20	BLOAD(1,1)	First load value
	.	.	.
	.	.	.
	.	.	.
	61 - 70	BTIME(1,4)	Fourth load time
	71 - 80	BLOAD(1,4)	Fourth load value

Notes:

(1) Up to 10 load cases can be input. A load case consists of one control line (i.e., Line 7.1) and one to five load data lines (i.e., Line 7.2) depending on the number of points input. Four points (i.e., load time, load value) are input on each line, therefore, if five points are required, two of Line 7.2's are read.

(2) A maximum of 20 load points can be defined.

(3) Load points are defined in terms of load and time and are linearly interpolated between points. If the load at time 0.0 is anything but 0.0, the problem becomes an initial value problem with the initial acceleration calculated as: ACCOLD = BLOAD (1,1)/(EQMASS (1)*SMASS). If the last point load time is less than the solution time, the program assumes a zero load for all points beyond the prescribed load.

12

EXECUTION INSTRUCTIONS

The program is designed to run on a minimum hardware platform of an IBM PC compatible personal computer having at least 512K memory and a math coprocessor. There are a number of ways to execute the program.

Installation

The SOLVER program is provided on a single diskette. The diskette contains:

SOLVER.EXE	The executable program
EX1.DAT	Example problem 1
EX2.DAT	Example problem 2
RUNSOLV.BAT	The batch execute file

These files should be copied to the hard disk or to another floppy disk before the program is used. The standard DOS COPY Command can be used:

COPY A:*.* C: For the hard disk
COPY A:*.* B: For the floppy disk

The program is now ready to run using one of the methods described below.

Standard Execution

The standard way of executing the program involves preparing an input file and running the program with the print output going to a file. The program assumes the input data are contained in the file SOLVER.DAT. The data can be prepared using any line or screen editor program, such as the DOS EDLIN editor. The user should prepare the input file using any descriptive file name then copying the file to SOLVER.DAT by using the standard DOS COPY Command. The program will write the output to SOLVER.OUT. The output file can be printed using the standard DOS PRINT Command.

The program is executed by typing SOLVER.

Input and Output Redirection

The user can use the DOS SET Command to redirect the input and/or the output. The default input and output names can be changed by:

SET SOLVER.DAT = your input file name
SET SOLVER.OUT = your output file name

then the program can be executed using your file names. CAUTION! The DOS redirection mechanism is active for as long as the computer is on. The SET Command stays set until the connection is broken through a system reboot or in the following manner:

SET SOLVER.DAT =
SET SOLVER.OUT =

Batch File Execution

The program can be run with the provided batch file (RUNSOLV.BAT) which takes care of the file manipulation. The user creates a data file as described before except that the file is stored using any descriptive file name and the extension .DAT. The batch file automatically changes the name to SOLVER.DAT, executes the program, and then changes the output SOLVER.OUT to the descriptive file name with the extension .OUT. The batch file is executed by the command:

RUNSOLV (descriptive file name without the extension .DAT)

CONCLUSIONS

The SOLVER program is a numerical tool that allows engineers to perform parametric studies on general SDOF systems and loadings. The engineer can vary the stiffness, mass, damping, and loading and then determine the effects on the response of the system. Examples of parametric studies are given in Appendixes A through E.

REFERENCE

1. John M. Biggs. Introduction to Structural Dynamics. New York, NY, McGraw-Hill Book Co., 1964.

2. ADINA User's Manual, ADINA Engineering, Report AE 84-1, December 1984.

Table 1. Consistent Units for SOLVER Input Terms

| Term	Length Force Time	Feet Kilo Pounds Seconds	Inches Pounds Milliseconds	Inches psi Milliseconds
Solution Time Step	$(time)$	(s)	(ms)	(ms)
Mass	$\left(\dfrac{force\text{-}time^2}{length}\right)$	$\left(\dfrac{k\text{-}s^2}{ft}\right)$	$\left(\dfrac{lbs\text{-}ms^2}{in}\right)$	$\left(\dfrac{psi\text{-}ms^2}{in}\right)$ or $\left(\dfrac{lbs\text{-}ms^2}{in^3}\right)$
Stiffness	$\left(\dfrac{force}{length}\right)$	$\left(\dfrac{k}{ft}\right)$	$\left(\dfrac{lbs}{in}\right)$	$\left(\dfrac{psi}{in}\right)$ or $\left(\dfrac{lbs}{in^3}\right)$
Resistance	$(force)$	(k)	(lbs)	(psi) or $\left(\dfrac{lbs}{in^2}\right)$
Yield Deflection	$(length)$	(ft)	(in)	(in)
Load Time	$(time)$	(s)	(ms)	(ms)
Load	$(force)$	(k)	(lbs)	(psi) or $\left(\dfrac{lbs}{in^2}\right)$

15
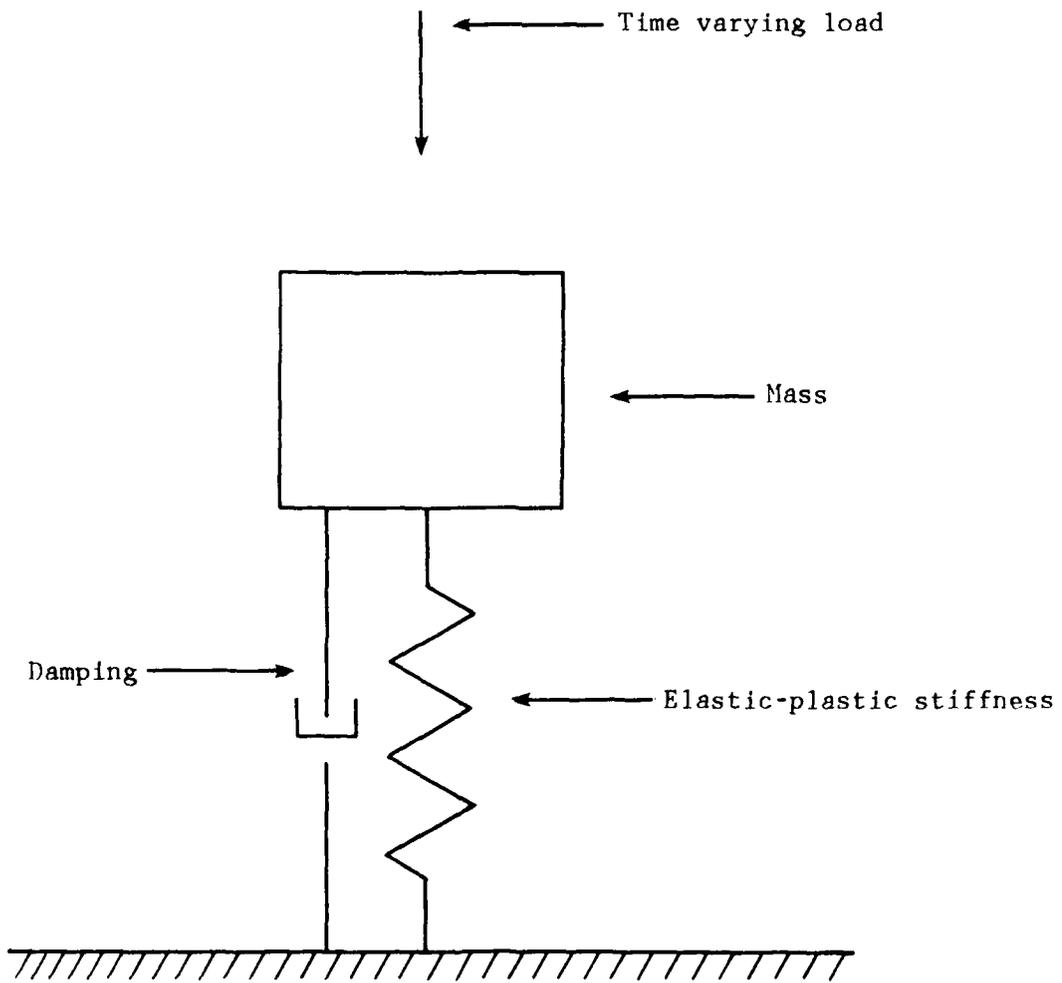
Figure 1. Single degree of freedom system.
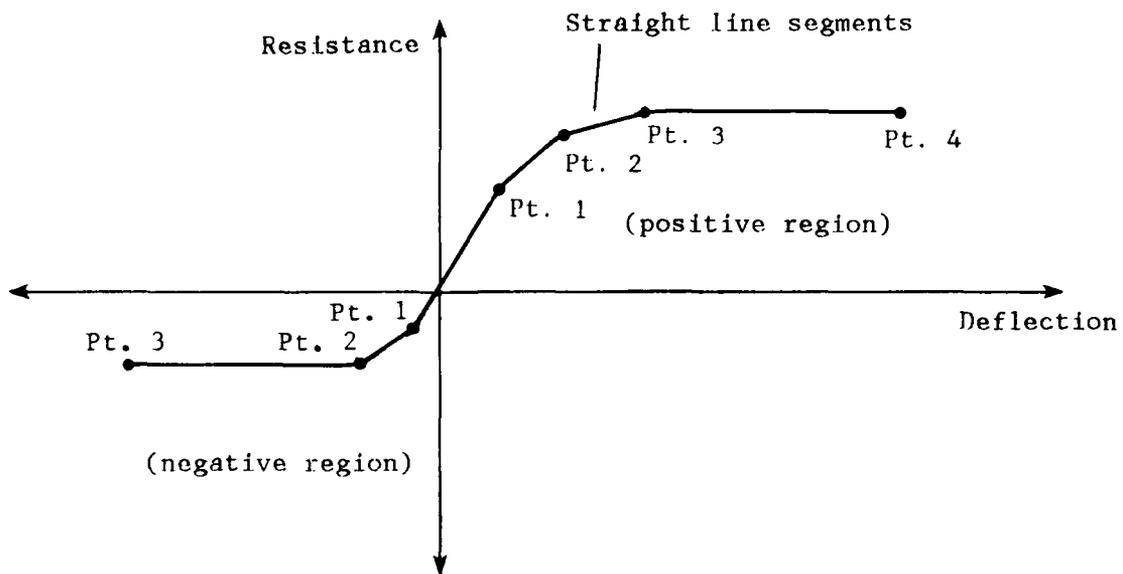
Figure 2.   Prescribed resistance-deflection curves for both positive
            and negative regions.
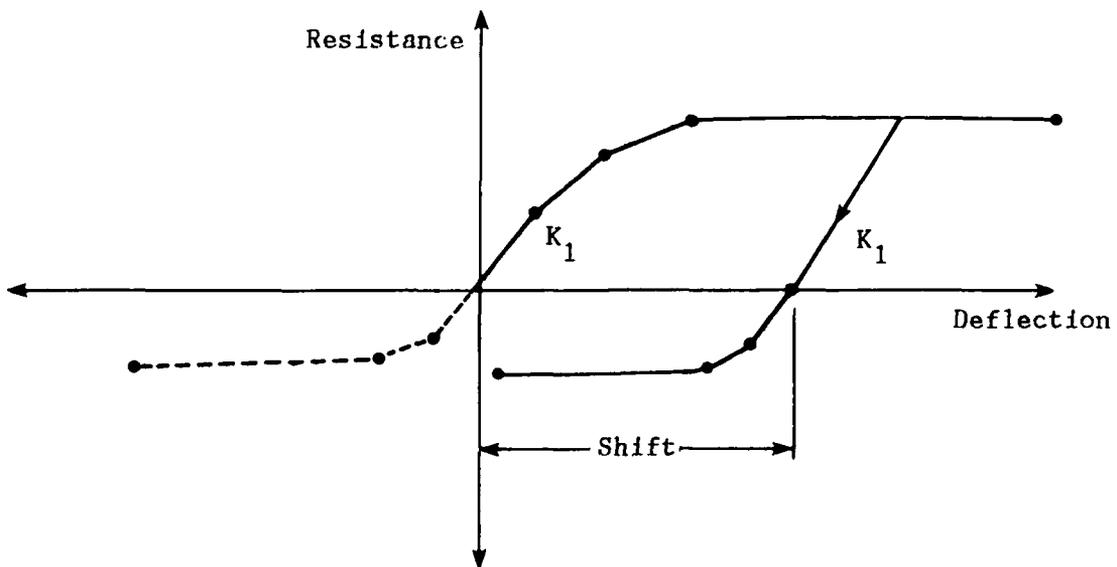
Figure 3.   Resistance-deflection curves showing shift upon rebound.
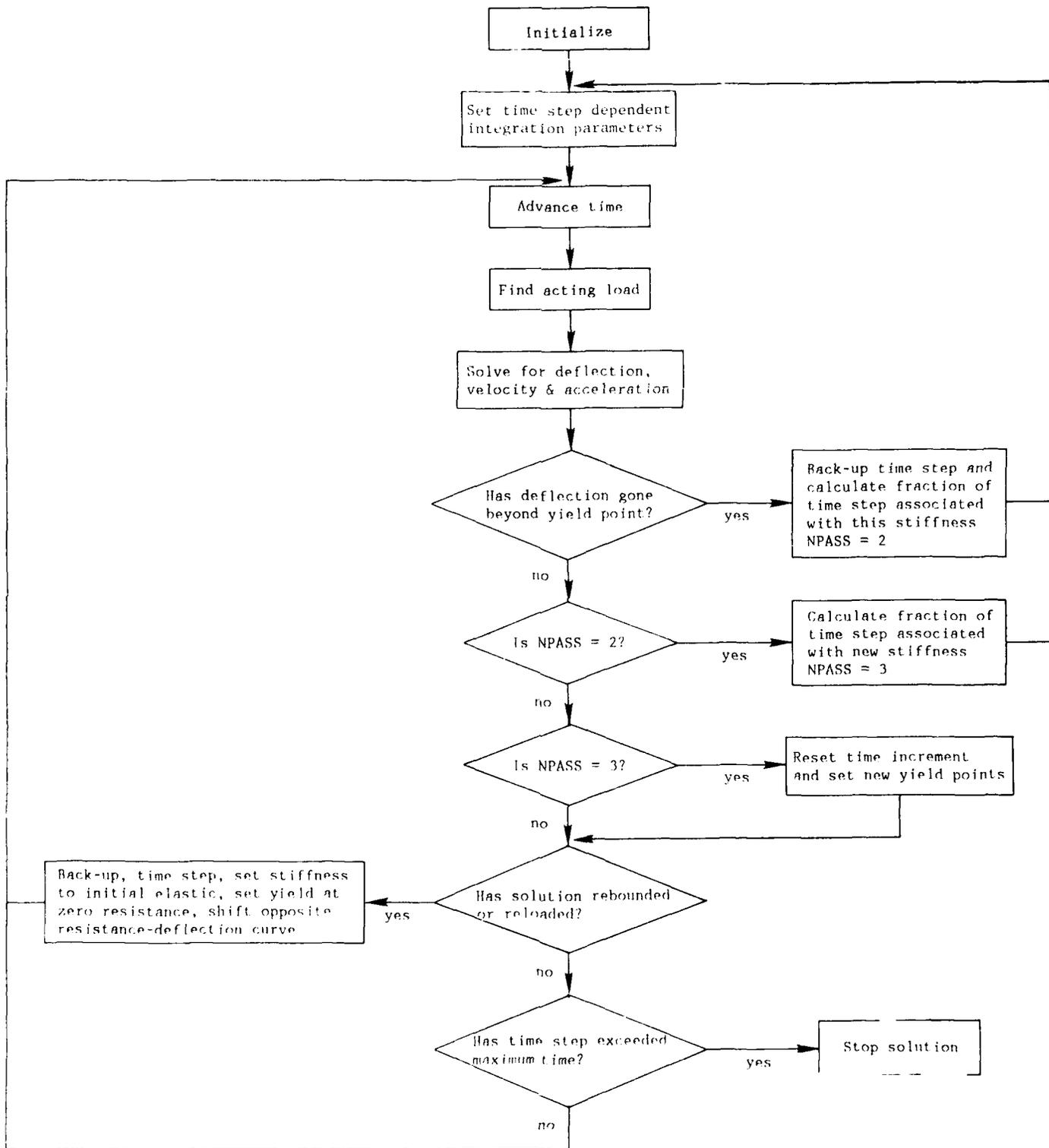
Figure 4. Newmark-beta solution method with plasticity and rebound.

18
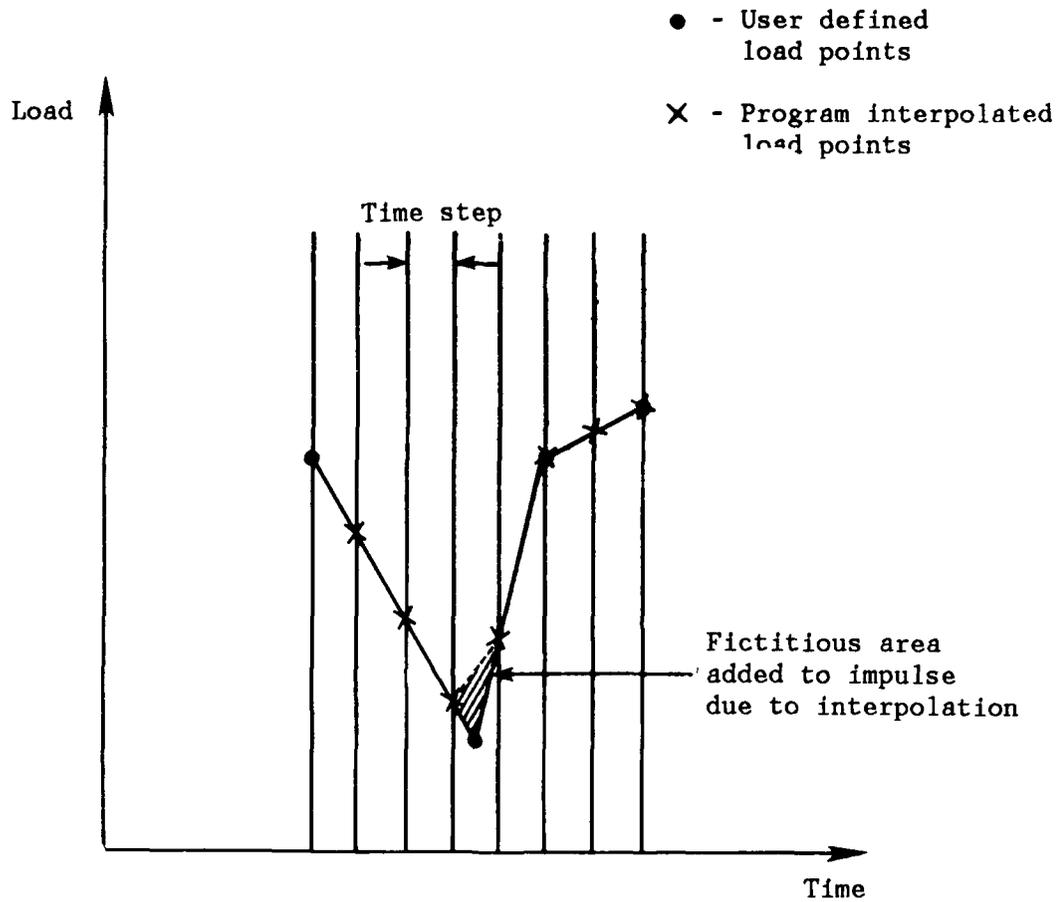
Figure 5. Example of load clipping due to linear interpolation.

19

SOLVER INPUT

Line

	1	5 6	10 11 15 16	20 21 25 26	30 31 35 36	40 41 45 46	50 51 55 56	60 61 65 66	70 71	80
1	SOLVE									
	METHOD	LODCAS	DTIME	TLIMIT	GAMMA	BETA		NPRINT		
2		DEFLTN	VELOCT	ACCELR						
3			SMASS	DAMPNG						
4	NSTIF1	NSTIF2								
5	MODE(N)	STIFF (N)	RESIST (N)	DEPYLD (N)	EQMASS (N)	DAMP (N)				
6	MODE(N)	STIFF (N)	RESIST (N)	DEFYLD (N)	EQMASS (N)	DAMP (N)				
7.1	NUMLOD	NUMLPT								
	BTIME (1,1)	BLOAD(1,1)	BTIME (1,2)	BLOAD (1,2)	BTIME (1,3)	BLOAD (1,3)	BTIME (1,4)	BLOAD (1,4)		
7.2										
1	STOP									

20

Figure 6. Input data form.

Appendix A

INITIAL CONDITIONS EVALUATION

An evaluation was made to determine the implementation of the initial conditions. A baseline run was made to calculate the maximum deflection to the resistance-deflection curve shown in Figure A-1 and a loading shown in Figure A-2. The input file is shown in Figure A-3. A sample of the output is shown in Figure A-4.

Three calculations were made using initial conditions obtained at various points in the baseline run. The first run was started at a point when the baseline run was still elastic. Its input file is shown in Figure A-5 and some of the results are shown in Figure A-6. The second run was started when the baseline run had just gone plastic. Its input file is shown in Figure A-7 and some of the results are shown in Figure A-8. The third run was started well after the baseline run had gone plastic. Its input file is shown in Figure A-9 and some of the results are shown in Figure A-10. The results show how SOLVER compares the initial deflection to the resistance-deflection curve and chooses the proper stiffness.

A summary of the tests on the initial conditions is given in Table A-1. Plots of the deflections, velocities, and accelerations are shown in Figure A-11. The results of these tests indicate that the initial conditions were properly implemented and can be used to restart a calculation up to the first rebound. Restarts made with initial conditions that represent a point during rebound or reload of the base-line solution will provide results to these initial conditions but will not properly replicate the baseline solution.

Table A-1. Results for Initial Condition Tests

Time (ms)	Initial Conditions			Maximums	
	Deflection (in)	Velocity (in/ms)	Acceleration (in/ms^2)	Σ Time (ms)	Deflection (in)
0	0	0	0	30.3	12.106
0.75	0.180	0.4444	0.4357	30.3	12.107
1.10	0.359	0.5683	0.2816	30.3	12.091
2.00	0.947	0.6942	-0.0020	30.3	12.095
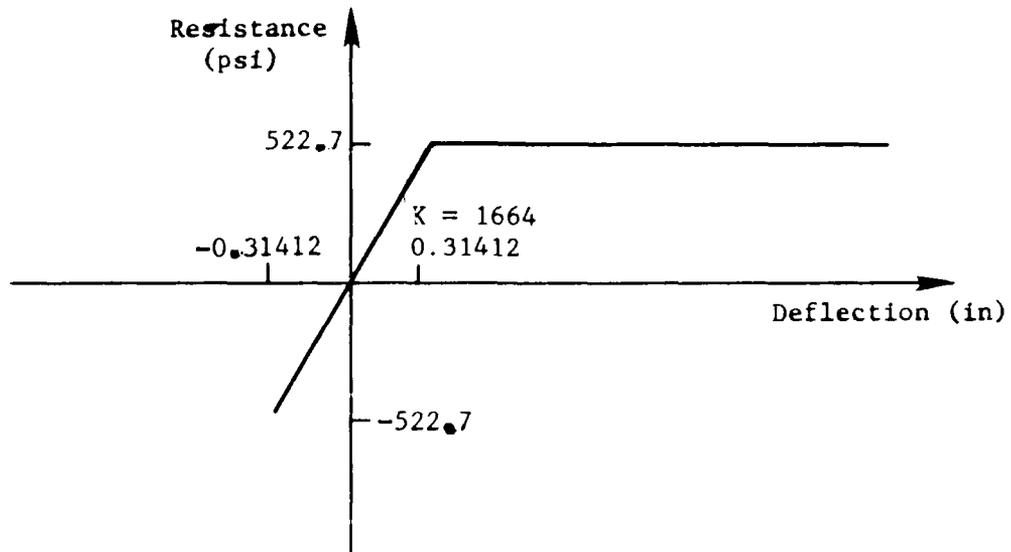
Figure A-1. Resistance-deflection curve.
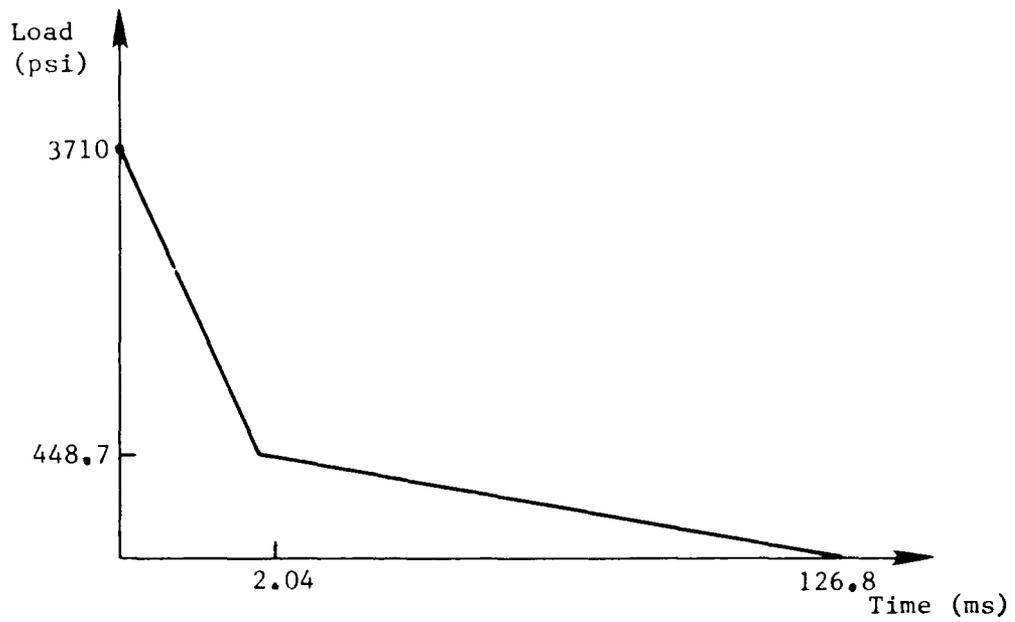
Figure A-2. Load curve.

```
SOLV    NATHAN HALE CYLINDER, NCEL LOAD
    1    1      0.05

    2    1    5074.0
    1    1664.0       522.7                      1.0       1.0
    3       0.0                   100.0          1.0       1.0
    1    1664.0      -522.7                      1.0       1.0
    1    4
       0.0    3710.0      2.04      448.7      126.8         0.0    1000.0       0.0
STOP
```

Figure A-3.   Input file for baseline run.

```
* * * * * SOLUTION RESULTS  * * * * * *
       STEP   TIME STIF DEFLECTION   VELOCITY      ACC RESISTANCE        LOAD
```

	STEP	TIME	STIF	DEFLECTION	VELOCITY	ACC	RESISTANCE	LOAD
ELAS	0	0.0000	1	0.000	0.0000	0.7312	0.00	3710.00
	1	0.0500	1	0.001	0.0362	0.7151	1.50	3630.07
	2	0.1000	1	0.004	0.0715	0.6985	5.98	3550.13
	3	0.1500	1	0.008	0.1060	0.6813	13.37	3470.20
	4	0.2000	1	0.014	0.1396	0.6635	23.58	3390.26
	5	0.2500	1	0.022	0.1723	0.6452	36.56	3310.33
	6	0.3000	1	0.031	0.2041	0.6264	52.22	3230.40
	7	0.3500	1	0.042	0.2350	0.6070	70.49	3150.46
	8	0.4000	1	0.055	0.2648	0.5872	91.28	3070.53
	9	0.4500	1	0.069	0.2937	0.5668	114.51	2990.60
	10	0.5000	1	0.084	0.3215	0.5460	140.10	2910.66
	11	0.5500	1	0.101	0.3483	0.5248	167.96	2830.73
	12	0.6000	1	0.119	0.3739	0.5031	198.00	2750.79
	13	0.6500	1	0.138	0.3986	0.4810	230.14	2670.86
	14	0.7000	1	0.159	0.4220	0.4585	264.27	2590.93
	15	0.7500	1	0.180	0.4444	0.4357	300.32	2510.99
	16	0.8000	1	0.203	0.4656	0.4125	338.17	2431.06
	17	0.8500	1	0.227	0.4856	0.3889	377.75	2351.13
	18	0.9000	1	0.252	0.5045	0.3650	418.93	2271.19
	19	0.9500	1	0.277	0.5221	0.3409	461.64	2191.26
	20	1.0000	1	0.304	0.5386	0.3164	505.77	2111.32
*CHG	21	1.0186	2	0.314	0.5444	0.3072	522.55	2081.54
	21	1.0500	2	0.331	0.5539	0.2974	522.55	2031.39
	22	1.1000	2	0.359	0.5683	0.2816	522.55	1951.46
	23	1.1500	2	0.388	0.5820	0.2659	522.55	1871.52
	24	1.2000	2	0.417	0.5949	0.2501	522.55	1791.59
	25	1.2500	2	0.448	0.6070	0.2344	522.55	1711.65
	26	1.3000	2	0.478	0.6184	0.2186	522.55	1631.72
	27	1.3500	2	0.509	0.6289	0.2028	522.55	1551.79
	28	1.4000	2	0.541	0.6386	0.1871	522.55	1471.85
	29	1.4500	2	0.573	0.6476	0.1713	522.55	1391.92
	30	1.5000	2	0.606	0.6558	0.1556	522.55	1311.99
	31	1.5500	2	0.639	0.6632	0.1398	522.55	1232.05
	32	1.6000	2	0.672	0.6698	0.1241	522.55	1152.12
	33	1.6500	2	0.706	0.6756	0.1083	522.55	1072.18
	34	1.7000	2	0.740	0.6806	0.0926	522.55	992.25
	35	1.7500	2	0.774	0.6848	0.0768	522.55	912.32
	36	1.8000	2	0.808	0.6883	0.0611	522.55	832.38
	37	1.8500	2	0.843	0.6909	0.0453	522.55	752.45
	38	1.9000	2	0.877	0.6928	0.0296	522.55	672.51
	39	1.9500	2	0.912	0.6939	0.0138	522.55	592.58
	40	2.0000	2	0.947	0.6942	-0.0020	522.55	512.65
	41	2.0500	2	0.981	0.6938	-0.0146	522.55	448.66
	42	2.1000	2	1.016	0.6930	-0.0146	522.55	448.48
	43	2.1500	2	1.051	0.6923	-0.0146	522.55	448.30
	44	2.2000	2	1.085	0.6916	-0.0147	522.55	448.12
	45	2.2500	2	1.120	0.6908	-0.0147	522.55	447.94
	46	2.3000	2	1.154	0.6901	-0.0147	522.55	447.76
	47	2.3500	2	1.189	0.6894	-0.0148	522.55	447.59
	48	2.4000	2	1.223	0.6886	-0.0148	522.55	447.41
	49	2.4500	2	1.258	0.6879	-0.0148	522.55	447.23
	50	2.5000	2	1.292	0.6871	-0.0149	522.55	447.05

```
***** MAXIMUM DEFLECTION REACHED
NUMBER OF STEPS TO MAXIMUM.............  606
TIME AT MAXIMUM........................       30.3000
MAXIMUM DEFLECTION.....................       12.106
```

Figure A-4. Selected results from baseline run.

```
SOLV    NATHAN HALE CYLINDER, NCEL LOAD, RESTART IN ELASTIC REGION
   1    1        0.05
    0.180     0.4444     0.4357
   2    1    5074.0
   1    1664.0      522.7                          1.0        1.0
   3       0.0                   100.0             1.0        1.0
   1    1664.0     -522.7                          1.0        1.0
   1    3
     0.0     2511.0       1.29      448.7     126.05         0.0
STOP
```

Figure A-5.   Input file for elastic restart run.

```
* * * * * SOLUTION RESULTS   * * * * * *
       STEP    TIME STIF DEFLECTION   VELOCITY        ACC  RESISTANCE        LOAD

ELAS    0    0.0000   1    0.180      0.4444        0.4357     299.52      2511.00
        1    0.0500   1    0.203      0.4656        0.4126     337.38      2431.07
        2    0.1000   1    0.227      0.4857        0.3891     376.95      2351.13
        3    0.1500   1    0.251      0.5045        0.3652     418.14      2271.20
        4    0.2000   1    0.277      0.5222        0.3410     460.85      2191.26
        5    0.2500   1    0.303      0.5386        0.3166     504.98      2111.33
*CHG    6    0.2695   2    0.314      0.5447        0.3070     522.55      2080.16
        6    0.3000   2    0.331      0.5539        0.2974     522.55      2031.40
        7    0.3500   2    0.359      0.5684        0.2816     522.55      1951.46
        8    0.4000   2    0.388      0.5821        0.2659     522.55      1871.53
        9    0.4500   2    0.417      0.5950        0.2501     522.55      1791.59
       10    0.5000   2    0.447      0.6071        0.2344     522.55      1711.66
       11    0.5500   2    0.478      0.6184        0.2186     522.55      1631.72
       12    0.6000   2    0.509      0.6289        0.2028     522.55      1551.79
       13    0.6500   2    0.541      0.6387        0.1871     522.55      1471.86
       14    0.7000   2    0.573      0.6476        0.1713     522.55      1391.92
       15    0.7500   2    0.605      0.6558        0.1556     522.55      1311.99
       16    0.8000   2    0.638      0.6632        0.1398     522.55      1232.05
       17    0.8500   2    0.672      0.6698        0.1241     522.55      1152.12
       18    0.9000   2    0.705      0.6756        0.1083     522.55      1072.19
       19    0.9500   2    0.739      0.6806        0.0926     522.55       992.25
       20    1.0000   2    0.773      0.6849        0.0768     522.55       912.32
       21    1.0500   2    0.808      0.6883        0.0611     522.55       832.38
       22    1.1000   2    0.842      0.6910        0.0453     522.55       752.45
       23    1.1500   2    0.877      0.6928        0.0296     522.55       672.52
       24    1.2000   2    0.911      0.6939        0.0138     522.55       592.58
       25    1.2500   2    0.946      0.6942       -0.0020     522.55       512.65
       26    1.3000   2    0.981      0.6938       -0.0146     522.55       448.66
       27    1.3500   2    1.015      0.6931       -0.0146     522.55       448.48
       28    1.4000   2    1.050      0.6924       -0.0146     522.55       448.30
       29    1.4500   2    1.085      0.6916       -0.0147     522.55       448.12
       30    1.5000   2    1.119      0.6909       -0.0147     522.55       447.94
       31    1.5500   2    1.154      0.6901       -0.0147     522.55       447.76
       32    1.6000   2    1.188      0.6894       -0.0148     522.55       447.59
       33    1.6500   2    1.223      0.6887       -0.0148     522.55       447.41
       34    1.7000   2    1.257      0.6879       -0.0148     522.55       447.23
       35    1.7500   2    1.292      0.6872       -0.0149     522.55       447.05


***** MAXIMUM DEFLECTION REACHED
NUMBER OF STEPS TO MAXIMUM.............  591
TIME AT MAXIMUM........................        29.5500
MAXIMUM DEFLECTION.....................        12.107
```

Figure A-6. Selected results for elastic restart run.

```
SOLV    NATHAN HALE CYLINDER, NCEL LOAD, RESTART IN PLASTIC REGION
  1    1       0.05
   0.359     0.5683     0.2816
   2    1     5074.0
   1    1664.0       522.7                      1.0      1.0
   3       0.0                      100.0       1.0      1.0
   1    1664.0      -522.7                      1.0      1.0
   1    3
     0.0     1951.0       0.94      448.7     125.70        0.0
STOP
```

Figure A-7. Input file for plastic restart run.

```
* * * * * SOLUTION RESULTS  * * * * * *
    STEP    TIME STIF DEFLECTION    VELOCITY        ACC RESISTANCE      LOAD

       0   0.0000   2   0.359      0.5683      0.2816    522.70    1951.00
       1   0.0500   2   0.388      0.5820      0.2657    522.70    1871.09
       2   0.1000   2   0.417      0.5949      0.2500    522.70    1791.18
       3   0.1500   2   0.447      0.6070      0.2342    522.70    1711.27
       4   0.2000   2   0.478      0.6183      0.2185    522.70    1631.36
       5   0.2500   2   0.509      0.6288      0.2027    522.70    1551.45
       6   0.3000   2   0.541      0.6386      0.1870    522.70    1471.54
       7   0.3500   2   0.573      0.6475      0.1713    522.70    1391.63
       8   0.4000   2   0.605      0.6557      0.1555    522.70    1311.72
       9   0.4500   2   0.638      0.6631      0.1398    522.70    1231.81
      10   0.5000   2   0.672      0.6697      0.1240    522.70    1151.90
      11   0.5500   2   0.705      0.6755      0.1083    522.70    1071.99
      12   0.6000   2   0.739      0.6805      0.0925    522.70     992.09
      13   0.6500   2   0.773      0.6847      0.0768    522.70     912.18
      14   0.7000   2   0.808      0.6882      0.0610    522.70     832.27
      15   0.7500   2   0.842      0.6908      0.0453    522.70     752.36
      16   0.8000   2   0.877      0.6927      0.0295    522.70     672.45
      17   0.8500   2   0.911      0.6938      0.0138    522.70     592.54
      18   0.9000   2   0.946      0.6941     -0.0020    522.70     512.63
      19   0.9500   2   0.981      0.6937     -0.0146    522.70     448.66
      20   1.0000   2   1.016      0.6929     -0.0146    522.70     448.48
      21   1.0500   2   1.050      0.6922     -0.0147    522.70     448.30
      22   1.1000   2   1.085      0.6915     -0.0147    522.70     448.12
      23   1.1500   2   1.119      0.6907     -0.0147    522.70     447.94
      24   1.2000   2   1.154      0.6900     -0.0148    522.70     447.76
      25   1.2500   2   1.188      0.6893     -0.0148    522.70     447.59
      26   1.3000   2   1.223      0.6885     -0.0148    522.70     447.41
      27   1.3500   2   1.257      0.6878     -0.0149    522.70     447.23
      28   1.4000   2   1.292      0.6870     -0.0149    522.70     447.05
```

***** MAXIMUM DEFLECTION REACHED
NUMBER OF STEPS TO MAXIMUM............. 584
TIME AT MAXIMUM..........................   29.2000
MAXIMUM DEFLECTION.......................   12.091

Figure A-8. Selected results from plastic restart run.

```
SOLV   NATHAN HALE CYLINDER, NCEL LOAD, RESTART IN PLASTIC REGION, NEG ACC
  1    1        0.05
   0.947    0.6942    -0.0020
   2    1    5074.0
   1    1664.0      522.7                    1.0        1.0
   3       0.0               100.0           1.0        1.0
   1    1664.0     -522.7                    1.0        1.0
   1    3
      0.0      512.6       0.04     448.7     124.80         0.0
STOP
```

Figure A-9.   Input file for negative acceleration, plastic restart run.

```
* * * * * SOLUTION RESULTS  * * * * * * *
    STEP   TIME STIF DEFLECTION   VELOCITY         ACC RESISTANCE       LOAD

      0   0.0000  2     0.947      0.6942      -0.0020     522.70       512.60
      1   0.0500  2     0.982      0.6938      -0.0146     522.70       448.66
      2   0.1000  2     1.016      0.6931      -0.0146     522.70       448.48
      3   0.1500  2     1.051      0.6923      -0.0147     522.70       448.30
      4   0.2000  2     1.086      0.6916      -0.0147     522.70       448.12
      5   0.2500  2     1.120      0.6909      -0.0147     522.70       447.94
      6   0.3000  2     1.155      0.6901      -0.0148     522.70       447.76
      7   0.3500  2     1.189      0.6894      -0.0148     522.70       447.59
      8   0.4000  2     1.224      0.6886      -0.0148     522.70       447.41
      9   0.4500  2     1.258      0.6879      -0.0149     522.70       447.23
     10   0.5000  2     1.292      0.6871      -0.0149     522.70       447.05
```

***** MAXIMUM DEFLECTION REACHED
NUMBER OF STEPS TO MAXIMUM.............. 566
TIME AT MAXIMUM.........................   28.3000
MAXIMUM DEFLECTION......................   12.095

Figure A-10. Selected results from negative acceleration, plastic
              restart run.

INITIAL CONDITIONS TESTS
DISPLACEMENTS
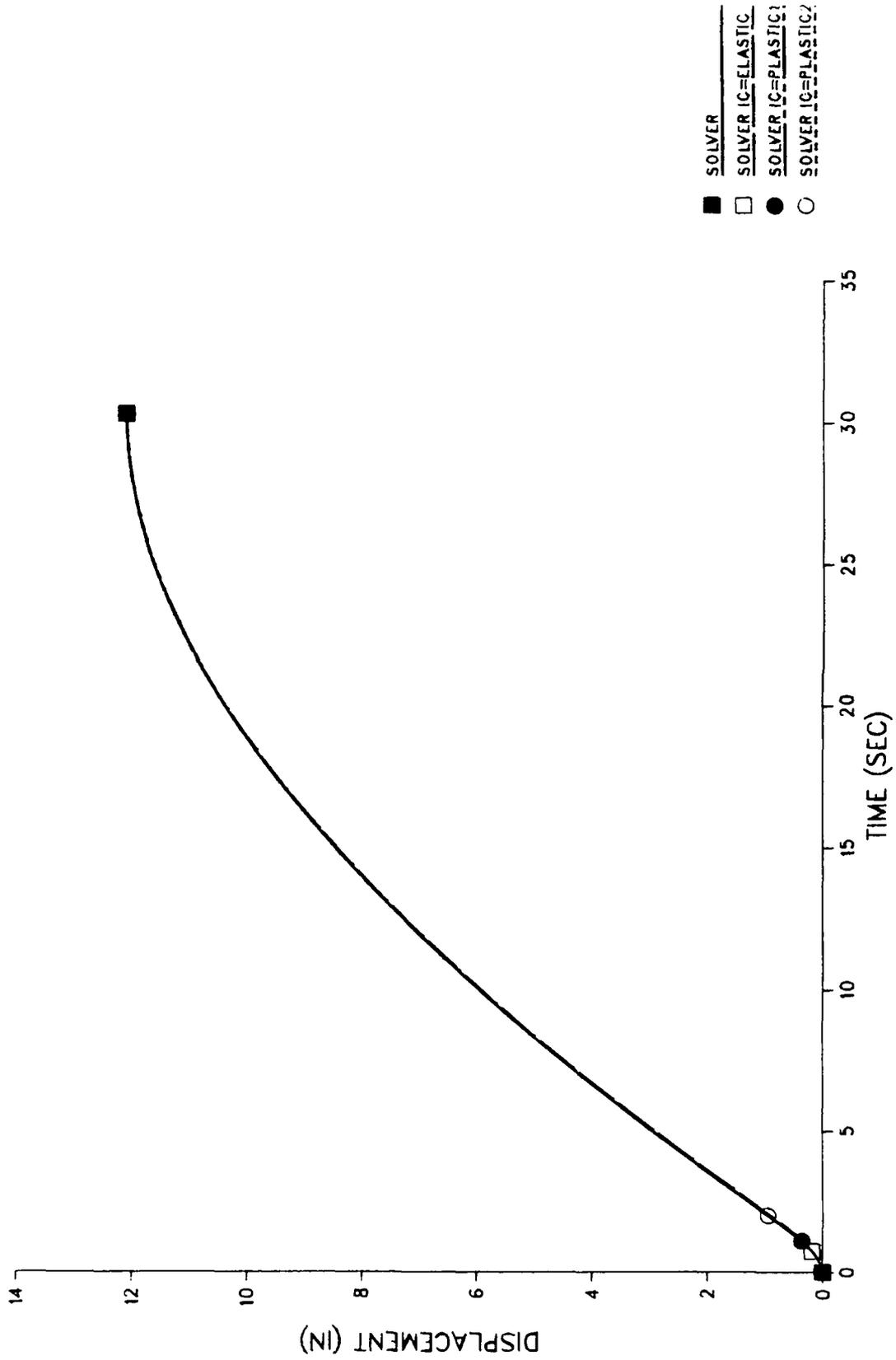

Figure A-11a. Displacement traces for initial condition tests.

INITIAL CONDITIONS TESTS
VELOCITIES

SOLVER
SOLVER IC=ELASTIC
SOLVER IC=PLASTIC1
SOLVER IC=PLASTIC2
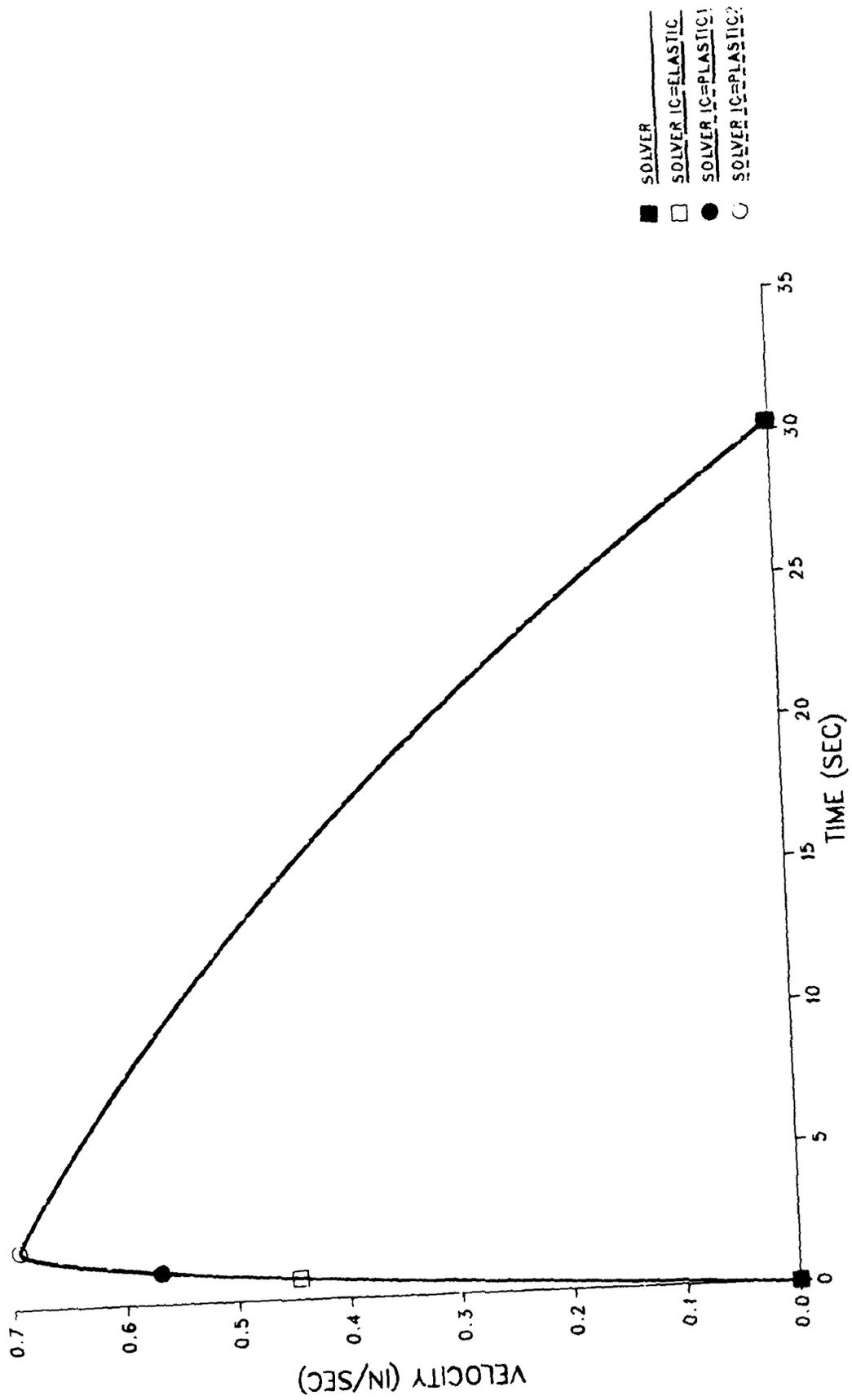
Figure A-11b. Velocity traces for initial conditions tests.

A-12

INITIAL CONDITIONS TESTS
ACCELERATIONS

SOLVER
SOLVER IC=ELASTIC
SOLVER IC=PLASTIC1
SOLVER IC=PLASTIC/

ACCELERATION (IN/SEC**2)

TIME (SEC)
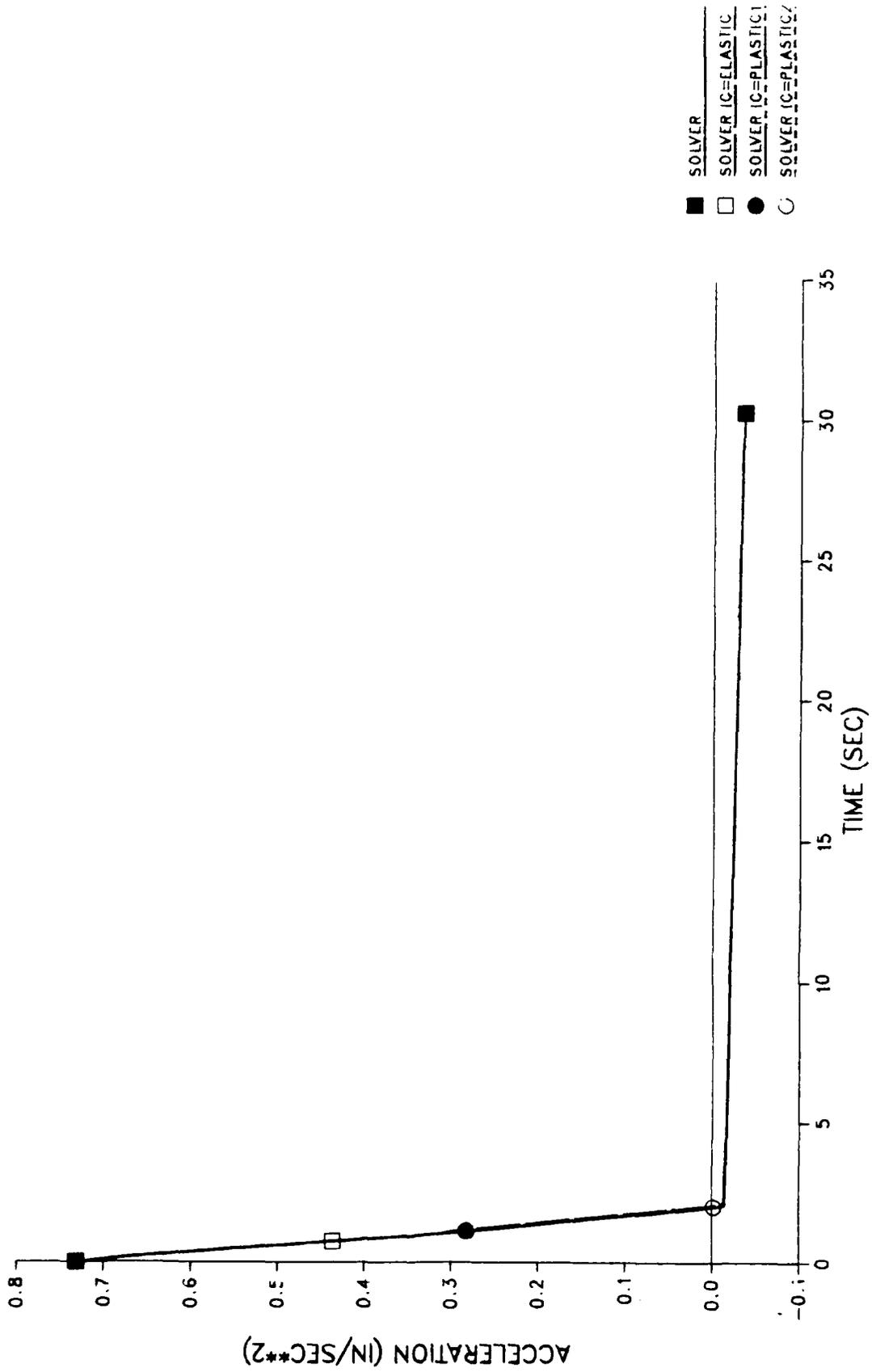
Figure A-11c. Acceleration traces for initial conditions tests.

Appendix B

YIELD POINT TESTS

The Newmark-beta solution scheme in SOLVER uses a simple fractioning technique at the yield points. This technique is tested against another technique that breaks up the time step into smaller, equal increments around yield points. Both of these techniques are then compared to the nonlinear truss element in the finite element program, ADINA (Ref 2). The resistance-deflection curve for SOLVER is shown in Figure B-1, the load in Figure B-2, and the input file in Figure B-3. The results, given in Table B-1, indicate that the functioning technique is adequate. The only limitation on this technique is that the time step should be sufficiently small so that:

- The time step fraction is accurate
- A time step doesn't exceed 2 yield points

Reducing the time step is the most effecient way to evaluate the accuracy of your solutions.

Table B-1. Yield Test Results

Technique	Time at Maximum (ms)	Maximum Displacement (in)	Solution Time (sec)
ADINA*	6.8	0.538	———
Fractional	6.8	0.537	0.11
10 steps at yield	6.8	0.536	0.13
100 steps at yield	6.8	0.537	0.17

*ADINA used BFGS equilibrium iterations and reformed the stiffness each step.
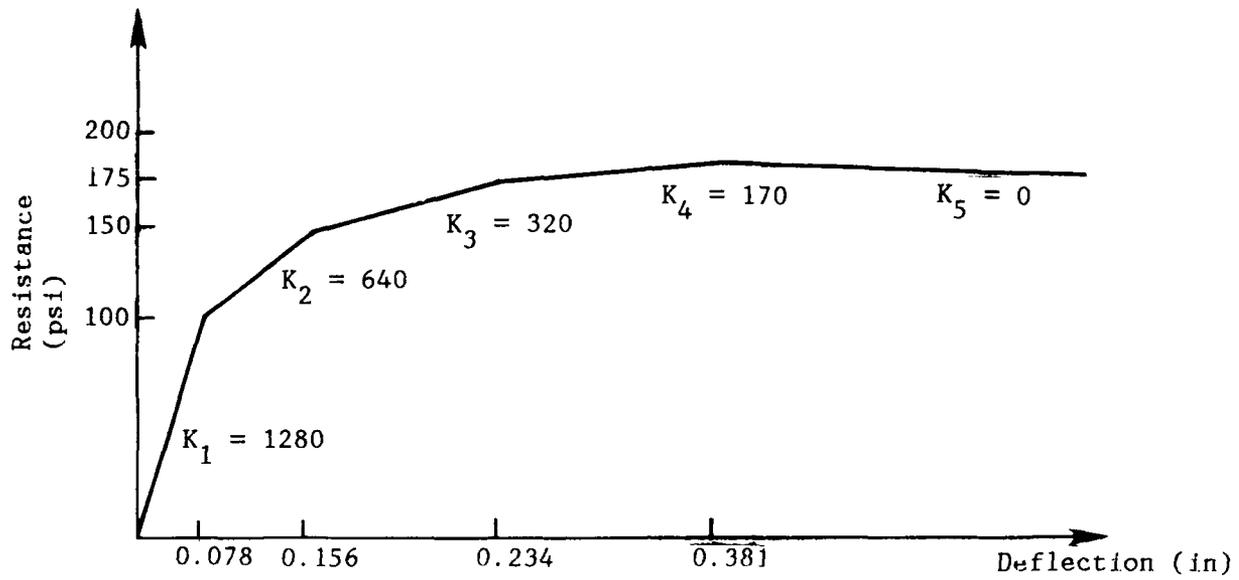
Figure B-1. Resistance-deflection curve for yield point tests.
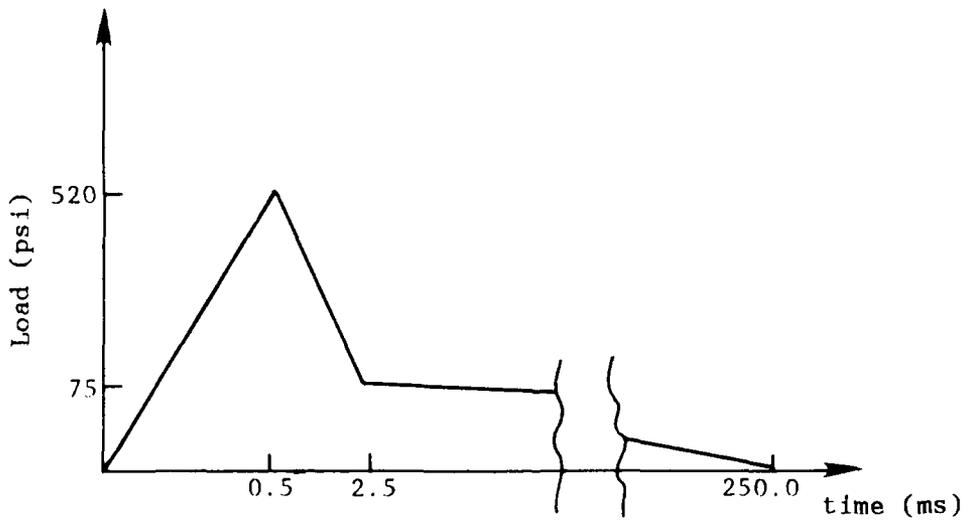
Figure B-2. Load curve for yield point tests.

```
SOLV YIELD POINT TEST, FRACTIONAL TIME STEPS
                0.1                                                    -1

    5    0    3775.0
    1    1280.0      100.0                        1.0        1.0
    2                150.0     0.15625            1.0        1.0
    2                175.0    0.234375            1.0        1.0
    2                200.0  0.3814325            1.0        1.0
    2                200.0      100.0            1.0        1.0
    1    4
        0.0        0.0        0.5      520.0      2.50      75.0      250.0      0.0
STOP
```

Figure B-3.   Input file for yield point tests.

Appendix C

DAMPING TESTS

An evaluation was made to determine whether damping was properly implemented in SOLVER. Two calculations were made on the same problem using 0 and 5% damping. These were compared to the nonlinear truss element in the finite element program ADINA (Ref 2). The resistance-deflection curve is shown in Figure C-1, the load in Figure C-2, and the input files in Figure C-3 and C-4. The results are given in Table C-1 and shown in Figure C-5. The SOLVER solution with 0% damping shows a slight amount of drift which is a result of the fractioning technique used at the yield points. The 5% damping solutions are, however, very close.

Table C-1. Results for Damping Tests

Damping	SOLVER		ADINA*	
	Time of Maximum (ms)	Maximum Deflection (in)	Time at Maximum (ms)	Maximum Deflection (in)
0%	26.0	5.89	26.0	5 68
5%	11.25	1.41	11.5	1.38

*ADINA used BFGS equilibrium iterations and reformed the stiffness every time step.
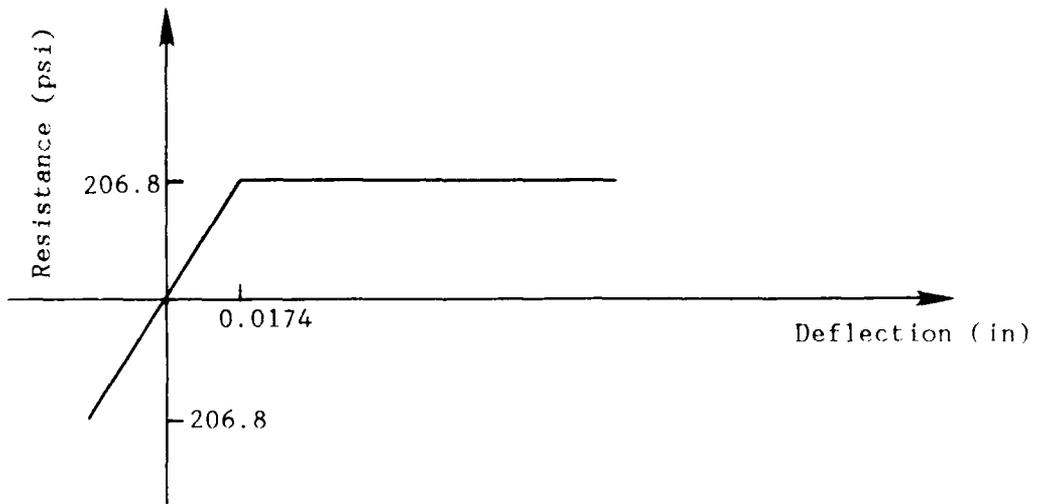
Figure C-1. Resistance-deflection curve for damping tests.
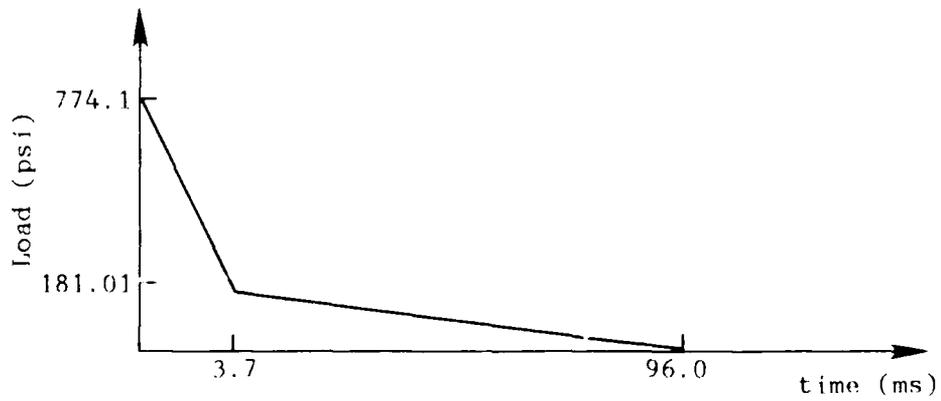

Figure C-2. Load curve for damping tests.

```
SOLVE     P-133 WALL B
   1    1         .05           30.

   2    1    2770.2
   1  11885.5      206.8                        1.0        1.
   3        .0                      100.        1.0        1.
   1  11885.5     -206.8                        1.0        1.
   1    4
        0.      774.1       3.70      181.0        96.0        0.      1000.        0.
STOP
```

Figure C-3.   Input file, 0% damping for damping tests.

```
SOLVE     P-133 WALL B    5 % DAMPING
   1    1         .05           30.

   2    1    2770.2          .05
   1  11885.5      206.8                        1.0        1.
   3        .0                      100.        1.0        1.
   1  11885.5     -206.8                        1.0        1.
   1    4
        0.      774.1       3.70      181.0        96.0        0.      1000.        0.
STOP
```

Figure C-4.   Input file, 5% damping for damping tests.

Figure C-5. Displacement traces for damping tests.

Appendix D

HARDENING TESTS

An evaluation was made of the hardening implementation in SOLVER. This involves a load that places the solution in the plastic range, unloads, and then reloads and continues into the plastic range. The resistance-deflection is shown in Figure D-1, the double pulse load in Figure D-2, and the input file in Figure D-3. SOLVER was compared to the nonlinear truss in the finite element program ADINA (Ref 2). The results for selected times are given in Table D-1. A plot of the deflection is shown in Figure D-4. The plot shows a slight separation in the solutions toward the third cycle.

Table D-1. Results for Hardening Tests

Time (sec)	Displacement		Error	Resistance		Error
	ADINA* (in)	SOLVER (in)		ADINA* (psi)	SOLVER (psi)	
5.00	0.559	0.559	0	162	161	< 1%
10.00	0.742	0.742	0	160	160	0
15.00	0.597	0.597	0	-25	-25	0
20.00	1.25	1.25	0	249	249	0
25.00	1.12	1.12	0	7	7	0
30.00	1.19	1.18	< 1%	96	92	4%
35.00	1.18	1.17	< 1%	87	89	2%

*ADINA used BFGS for equilibrium iterations and reformed stiffness every step.
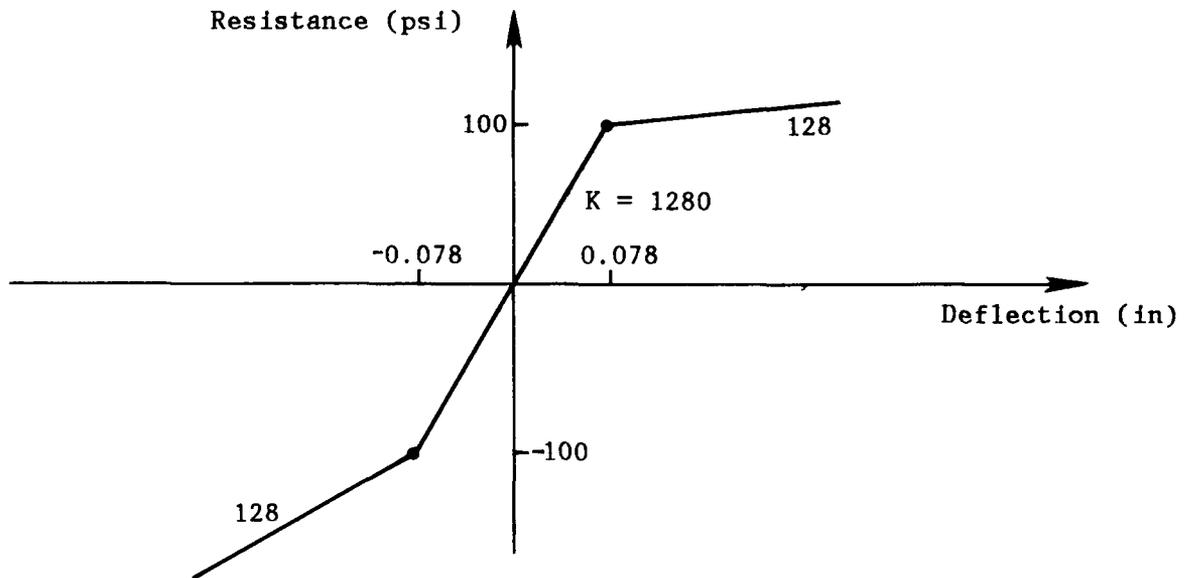
Figure D-1.   Resistance-deflection curve for harding tests.
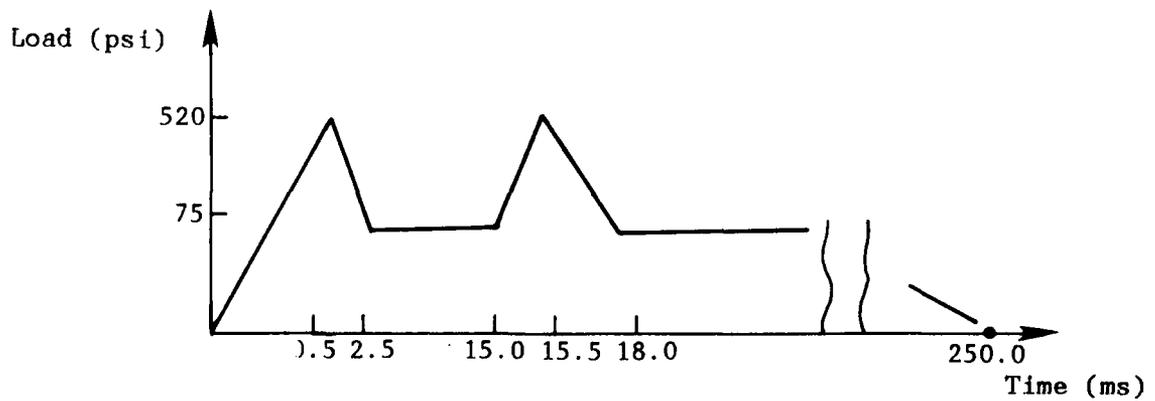
Figure D-2.   Load curve for hardening tests.

```
SOLV   HARDENING TEST
                    0.1      35.0                                              00

    2    2    3775.0      0.00
    1    1280.0      100.0                        1.0        1.0
    3     128.0                   100.0           1.0        1.0
    1    1280.0     -100.0                        1.0        1.0
    3     128.0                  -100.0           1.0        1.0
    1    7
        0.0        0.0       0.5      520.0         2.5       75.0      15.0       75.0
       15.5      520.0      18.0       75.0       250.0        0.0
STOP
```

Figure D-3.   Input file for hardening tests.

HARDENING TEST
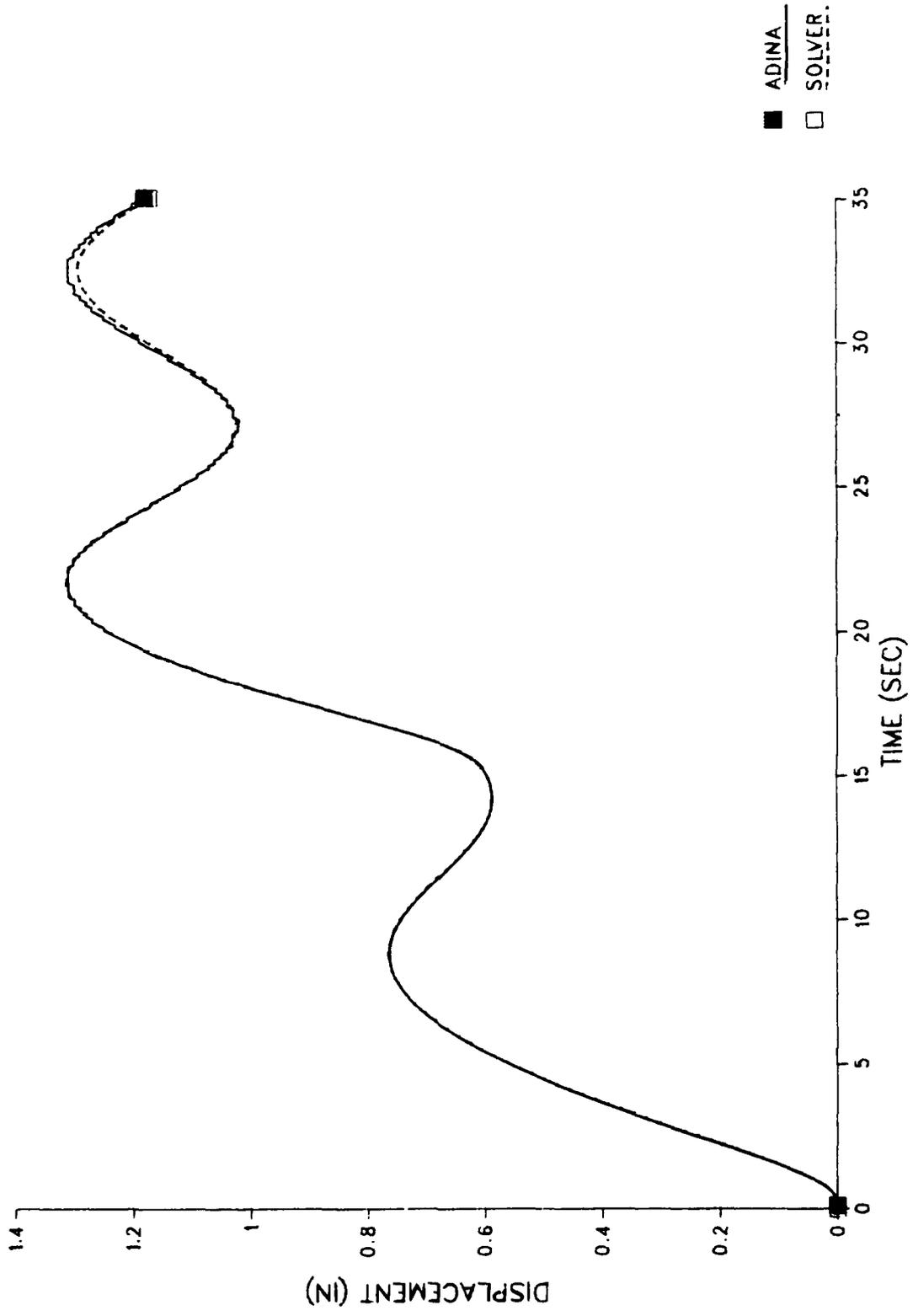
Figure D-4. Deflection traces for hardening tests.

Appendix E

Load-Mass Factor Tests

An evaluation was made in the use of the load-mass factors in elastic-plastic calculations. The resistance-deflection curve and the loadings shown in Figures E-1 and E-2 were made for a range of loadings. The first uses an average load-mass factor that was calculated assuming a ductility of 4.0. The second uses the appropriate load-mass factor for the portion of the resistance-deflection curve.

The SOLVER results are compared with the ADINA (Ref 2) finite element program's nonlinear truss using the BFGS equilibrium iterations, reforming the stiffness and restarts for changing the mass. Both results are shown in Table E-1. The maximum times and displacements for each test of load-mass factors compare favorably between the programs. Both results, however, show a significant reduction in maximum displacement when the appropriate load-mass factors are employed. This reduction appears to be greater as the load becomes more impulsive.

This evaluation demonstrates the proper implementation of the load-mass factors and the advantages of employing the appropriate factors in the calculations.

Table E-1. Load-Mass Factor Test Results

| $\frac{B}{r_u}$	$\frac{t_d}{T_n}$	B (lb)	t_d (sec)	SOLVER						ADINA					
				Average K_{LM}		Exact K_{LM}		% Error		Average K_{LM}		Exact K_{LM}		% Error	
				t_m (sec)	X_m (in)	t_m (sec)	X_m (in)			t_m (sec)	X_m (in)	t_m (sec)	X_m (in)		
1.00	4.40	520,000	0.2000	0.0535	5.845	0.0500	4.863	20.2		0.0537	5.932	0.0500	4.931	20.3	
1.25	1.40	650,000	0.0630	0.0415	5.803	0.0390	4.796	21.0		0.0410	5.795	0.0387	4.790	21.0	
1.67	0.73	866,666	0.0330	0.0335	5.919	0.0315	4.836	22.4		0.0331	5.904	0.0313	4.828	22.3	
2.5	0.41	1,300,000	0.0183	0.0275	5.875	0.0225	4.639	26.6		0.0274	5.851	0.0251	4.629	26.4	
5.0	0.18	2,600,000	0.0083	0.0245	5.890	0.0210	4.280	37.6		0.0239	5.825	0.0206	4.235	37.5	
10.0	0.09	5,200,000	0.0040	0.0226	5.785	0.0188	4.044	43.1		0.0224	5.736	0.0186	4.011	43.0	
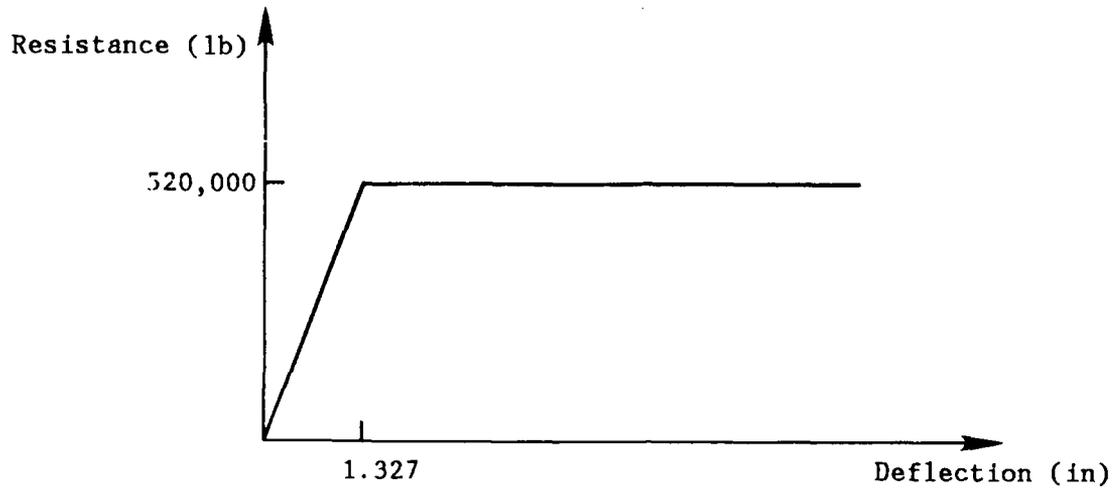
Figure E-1. Resistance-deflection curve.
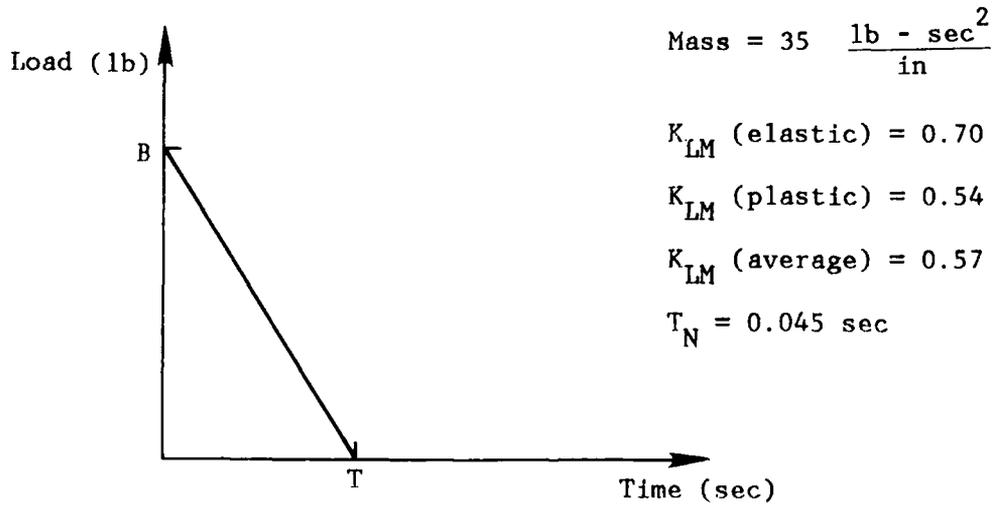
Mass = 35 $\dfrac{\text{lb} - \text{sec}^2}{\text{in}}$

K_{LM} (elastic) = 0.70

K_{LM} (plastic) = 0.54

K_{LM} (average) = 0.57

T_N = 0.045 sec

Load - Time Curve

Figure E-2. Load-mass factor problem definition

FEEDBACK REPORT

The Naval Civil Engineering Laboratory is fully dedicated to supporting GEMS users. A primary requirement for this task is to establish a priority listing of user requirements. It would be of great value to the development of new software if you, the user, would complete the feedback questions below. Since each individual user may have specific requirements, please reproduce this page as many times as necessary.

Please circle the number that best applies in questions 1 through 4, complete the other questions, fold at tic marks, and mail to NCEL with franked label on reverse side or to address at bottom of page.

1. Was the software beneficial (productive)?

    No benefit   0   1   2   3   4   5   6   7   8   9   10   Very beneficial

2. Was it easy to use (user friendly)?

    Difficult   0   1   2   3   4   5   6   7   8   9   10   Very easy

3. Does this software make decisions more reliable?

    No   0   1   2   3   4   5   6   7   8   9   10   Yes

4. Does it better document the design?

    No   0   1   2   3   4   5   6   7   8   9   10   Yes

5. Did it save time?

    Yes___   No___   Estimated percent saved_____

6. What would make future software more user friendly?

7. What further support would you like to have on the GEMS system?

8. What other comments or remarks would you like to add?

Activity _____
Telephone _____

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